Formal Method for Microgrids Stability and Control

BNL's Smart Grid Workshop

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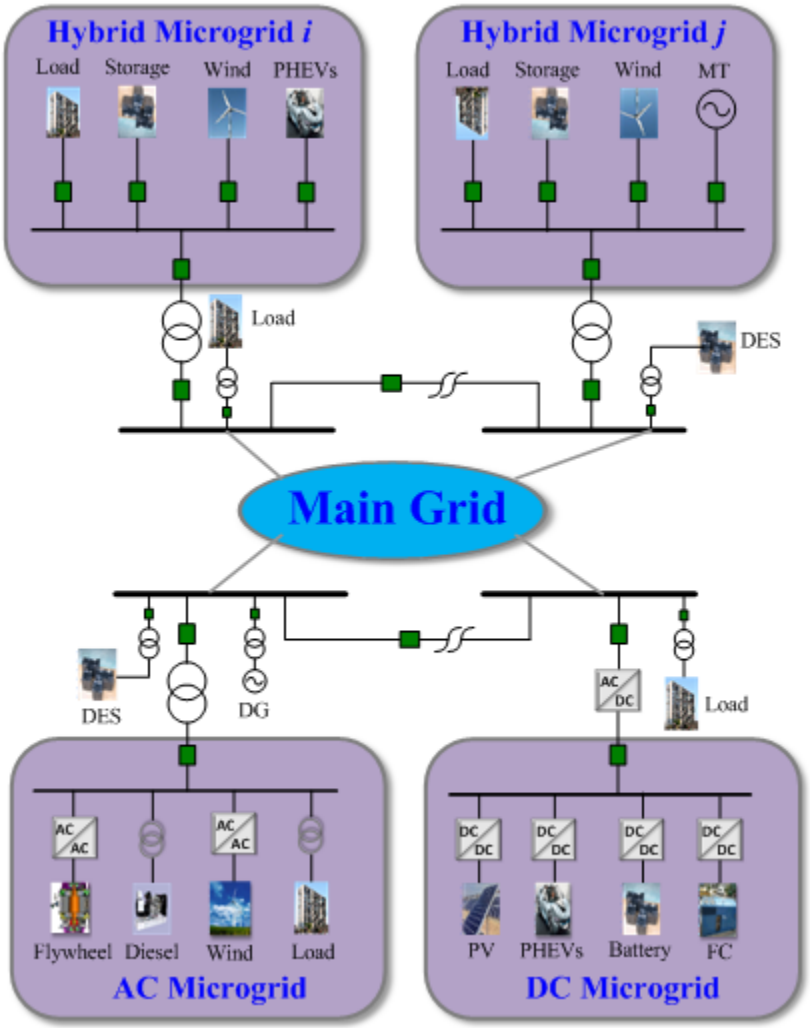
Technical Challenges

- MICROGRIDS (MGs) are active clusters of distributed generators (DGs), loads and energy storage, and other onsite electric components.
- Stability assessment and control in a networked system
- Issue of uncertainties
  - Weather conditions
  - Load & electrical vehicle
  - Control parameters
  - Interaction between networked microgrids



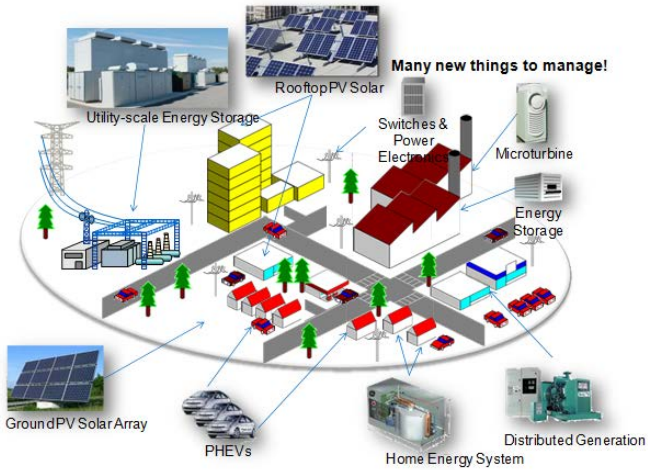
Networked Microgrids

Formal Method

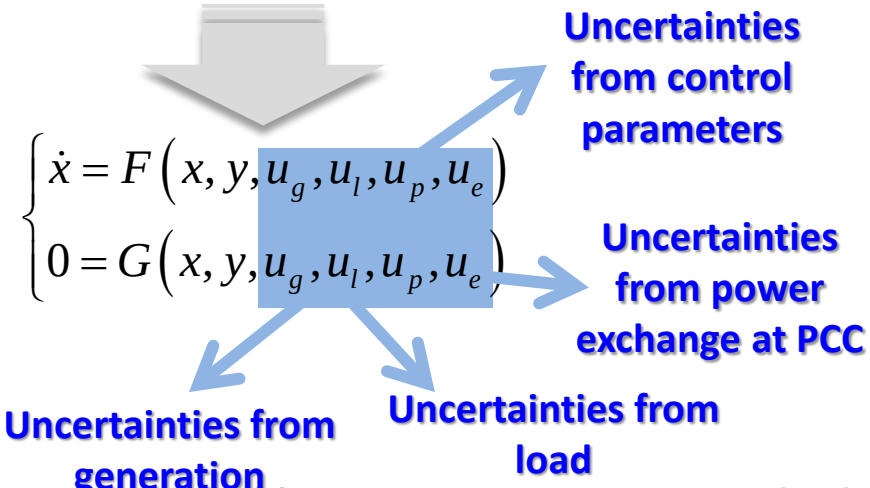
Analysis Methods	Pros	Cons
Numerical Simulation	• Easy to implement • Provide satisfying results in specific scenarios	■ Inefficient in considering uncertainties with exponential complexity ■ Stability margin unattainable through trajectories
Formal Method: Combining the advantages		
Direct Methods	• Provide stability regions from which the system can return to the original point • Quickly check if control actions are capable of stabilizing the system	■ Lyapunov functions are not easy to obtain ■ Cannot check if phase, voltage, or frequency constraints are met

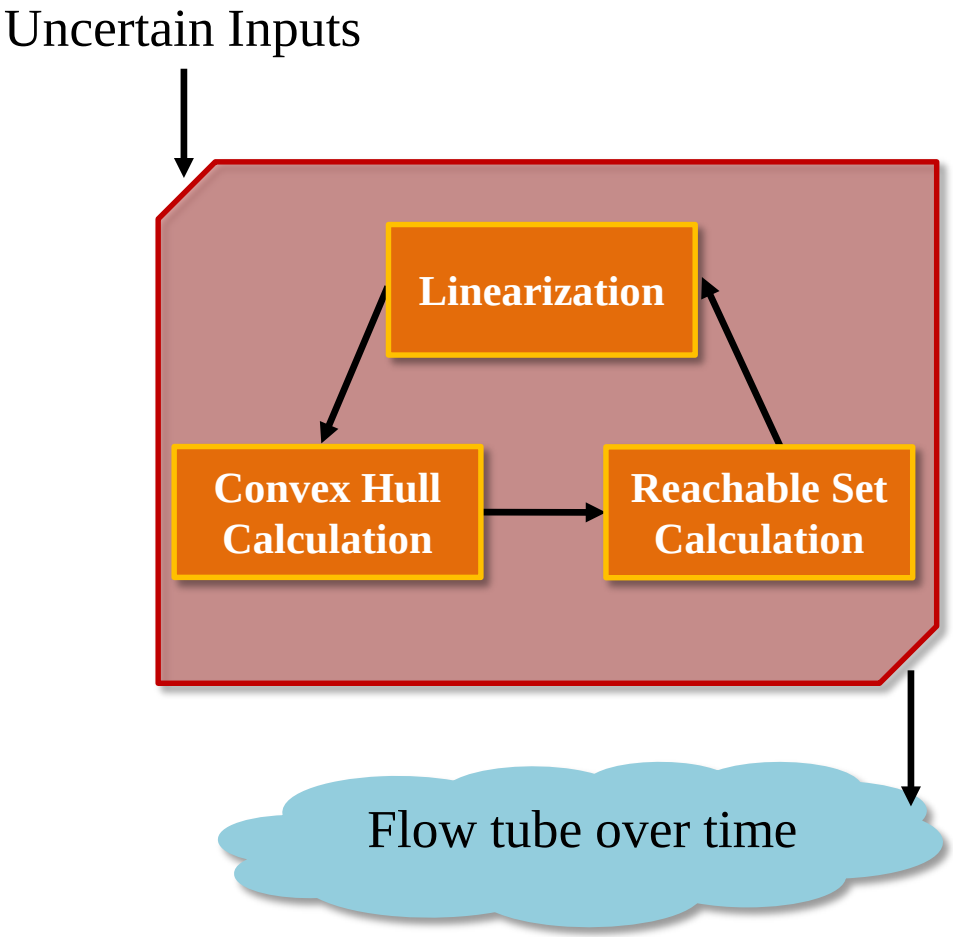
Formal Method: Understanding the Theory

- Single MG analysis

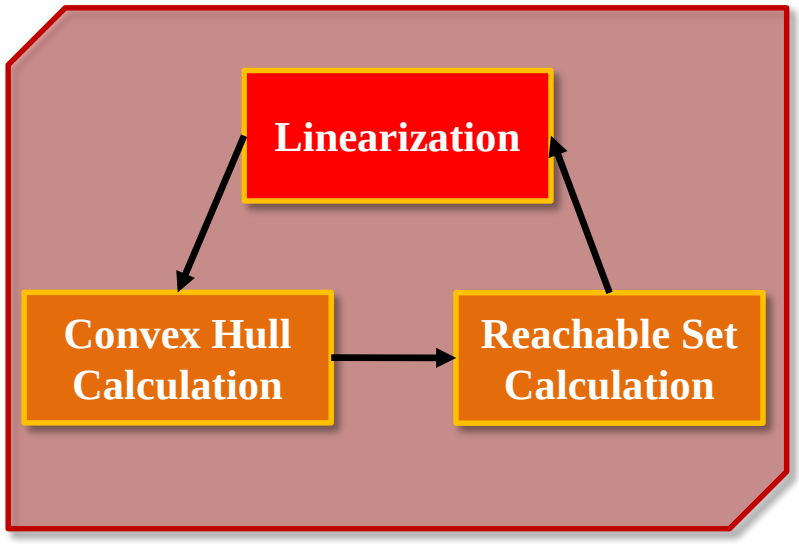


Source: Google microgrid





Formal Method: Understanding the Theory

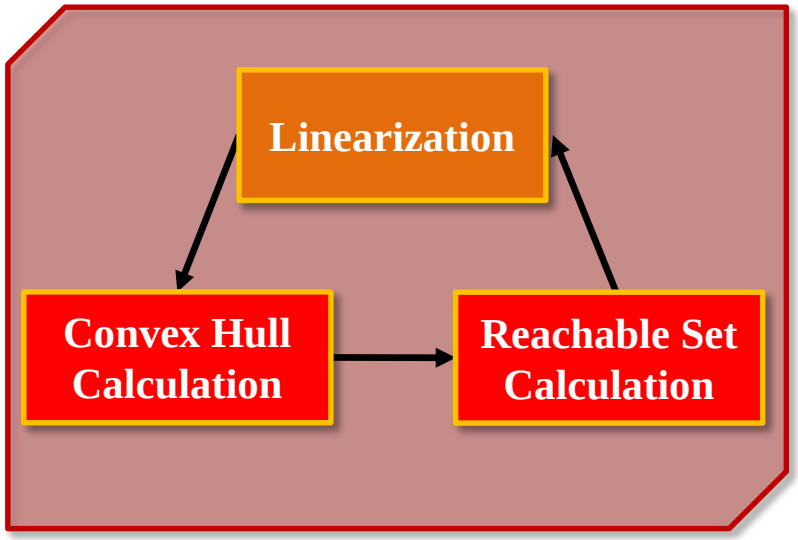


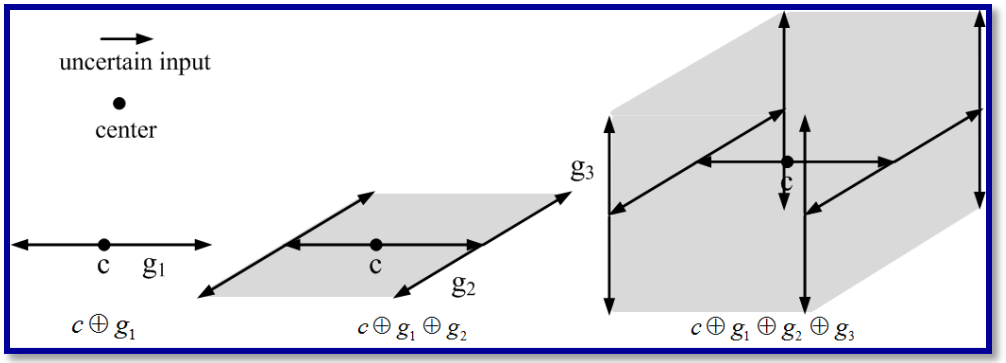
Flowchart of the formal method

$$\Delta\dot{x} = \left(A_1 - B_1 B_2^{-1} A_2\right)\Delta x$$
$$+\left(C_1 - B_1 B_2^{-1} C_2\right)\Delta u_g \rightarrow \text{Generation}$$
$$+\left(D_1 - B_1 B_2^{-1} D_2\right)\Delta u_l \rightarrow \text{Load}$$
$$+\left(E_1 - B_1 B_2^{-1} E_2\right)\Delta u_p \rightarrow \text{Control Parameter}$$
$$+\left(F_1 - B_1 B_2^{-1} F_2\right)\Delta u_e \rightarrow \text{Power Exchange}$$
$$+\sigma_{FG}$$

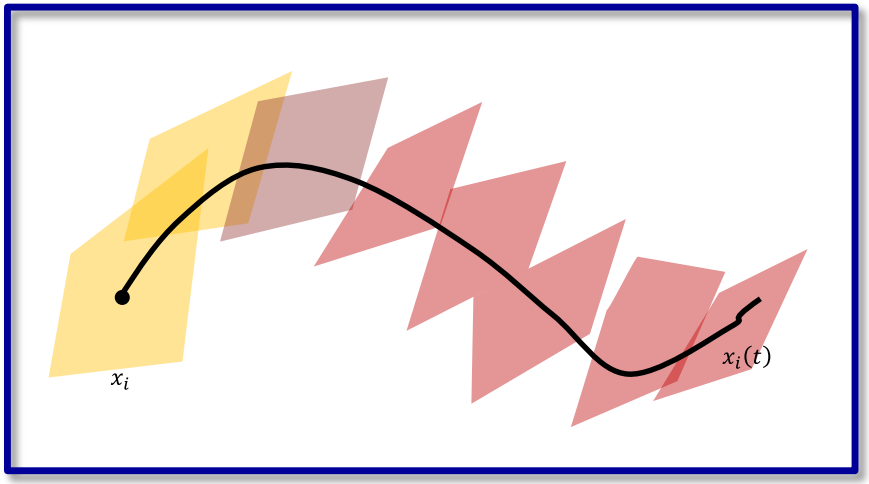
Linearization of nonlinear MG system

Formal Method: Understanding the Theory



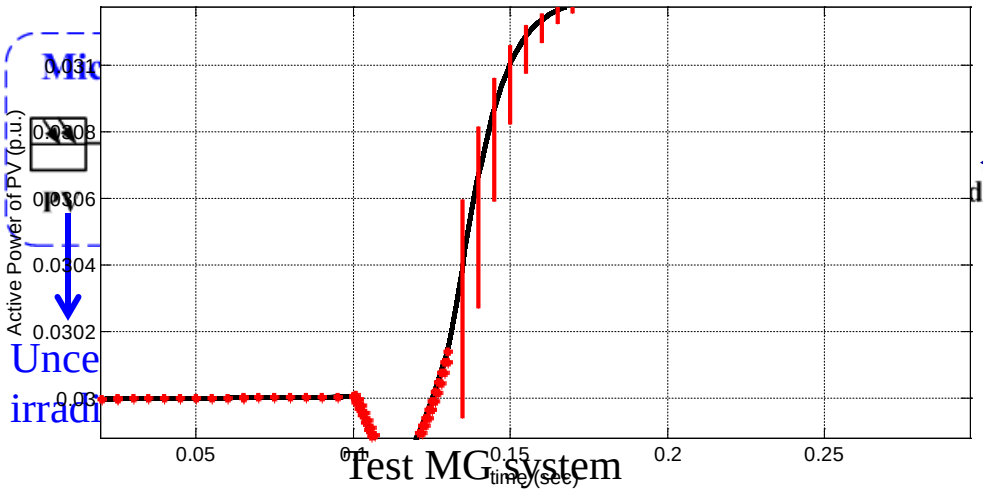


Construction of three dimensional zonotope

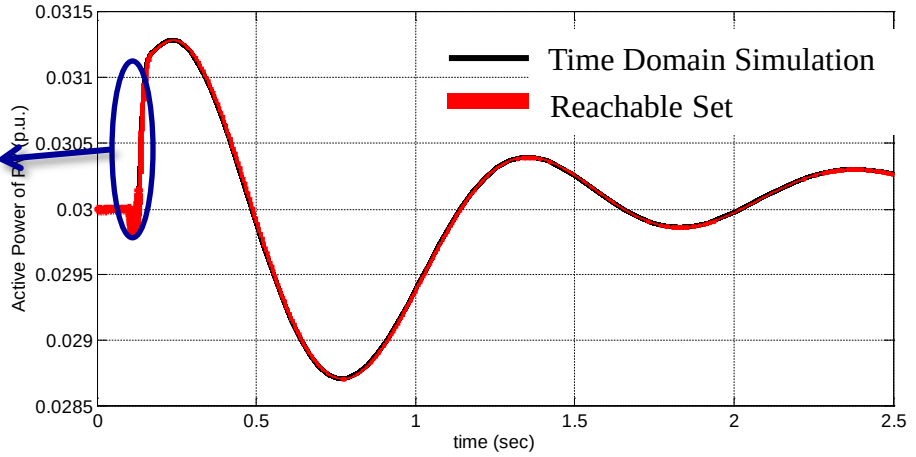


Reachable Set Calculation Process

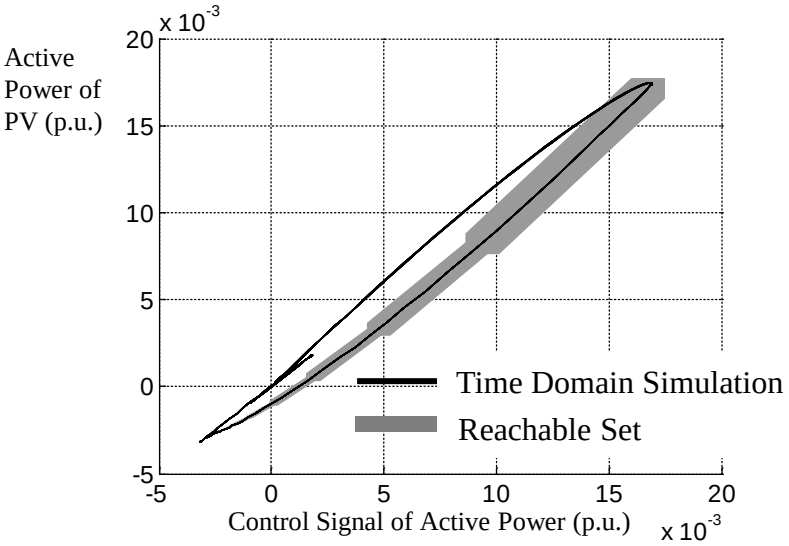
Formal Analysis Results



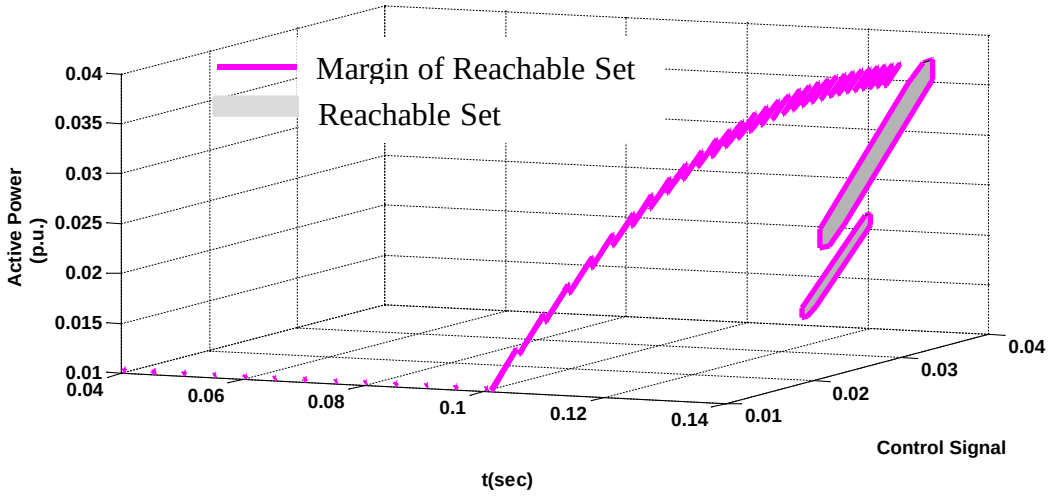
Test MG system



2D reachable set in time domain



Reachable set between active power and its control signal



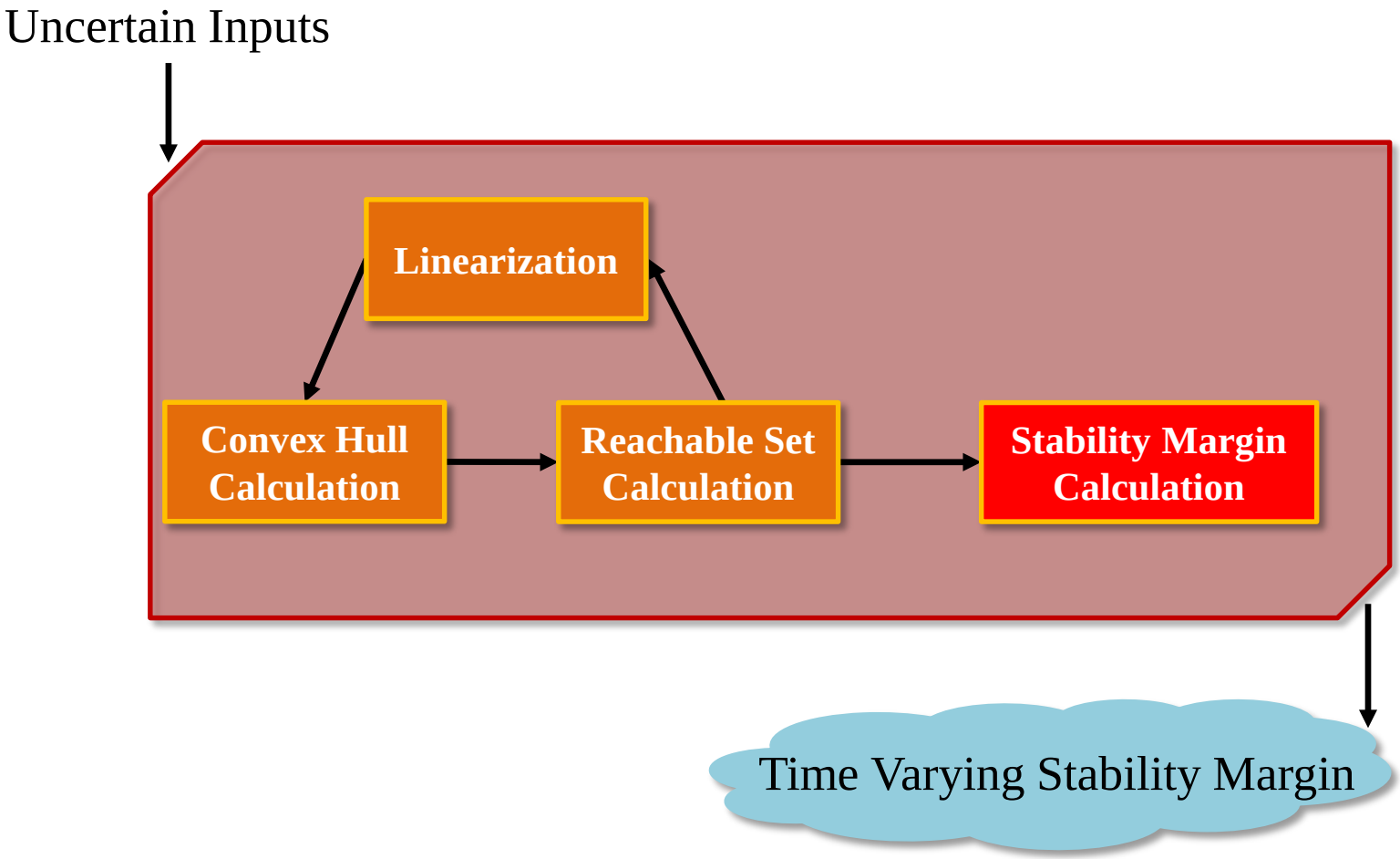
3D section of reachable set in time domain

Applications of Formal Method
--Stability Margin Calculation and Analysis

- How far away is a microgrid from the stability margin?
- What formal method can offer
  - A criterion to estimate acceptable operation range
  - Quantitative measure of MG stability margin
  - Understanding of the impact of uncertainties
  - Transfer capability among MGs
  - Design and verification of MGs control

Formal Method Potential Application

--Stability Margin Calculation and Analysis



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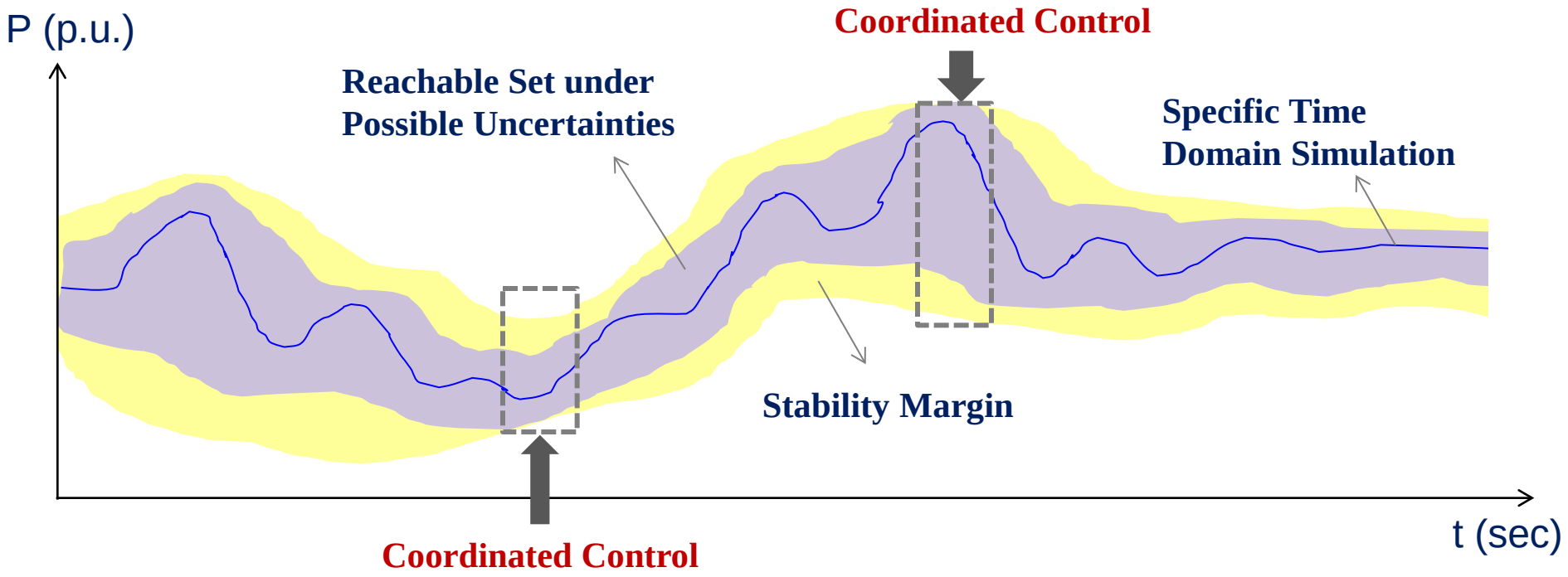
--Stability Margin Calculation and Analysis



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